Electronic Packaging Enabling the Future of Semiconductors

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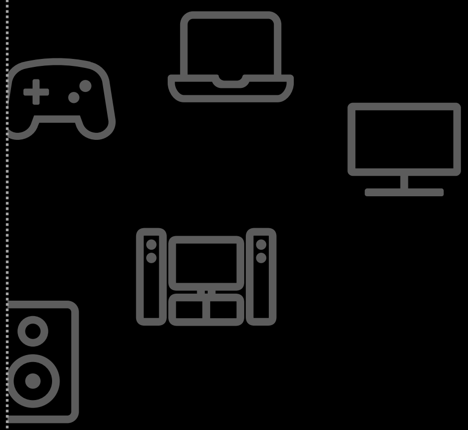
The world has changed…

2000 | 2010 | 2020 | 2030+

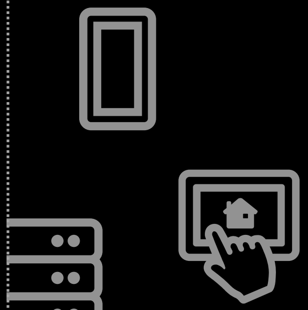
Analog world

Laptops
Desktops
Mobiles
Game consoles
Home audio & video



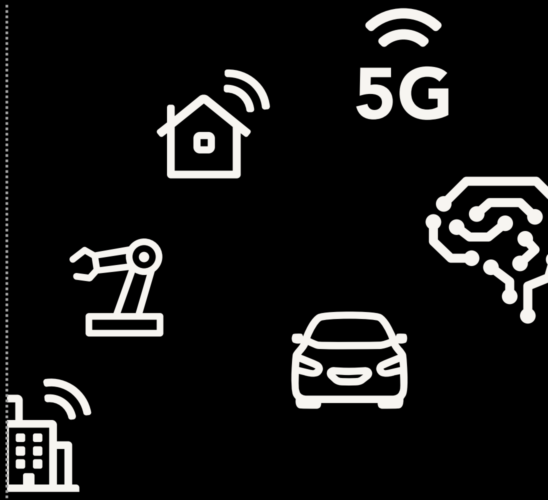
On-demand world

Smartphones
Tablets
Data-center servers



Robotics age

Artificial Intelligence from Cloud to Edge
Smart connected devices
Smart factories and homes
Smart connected cars



A world that anticipates and automates is upon us

Robots with AI agents everywhere

Sense	Think	Connect	Act

Everything safe & secure

Scalable system solutions

Let's build these systems

Hardware + **Software & Tools**

Sense
The environment

Think
Compute thought

Connect
To the cloud and get data

Act
Take action

1. Trust – safety & security

2. Low power architectures

3. AI & machine learning

But what are the implications for packaging?

Technology

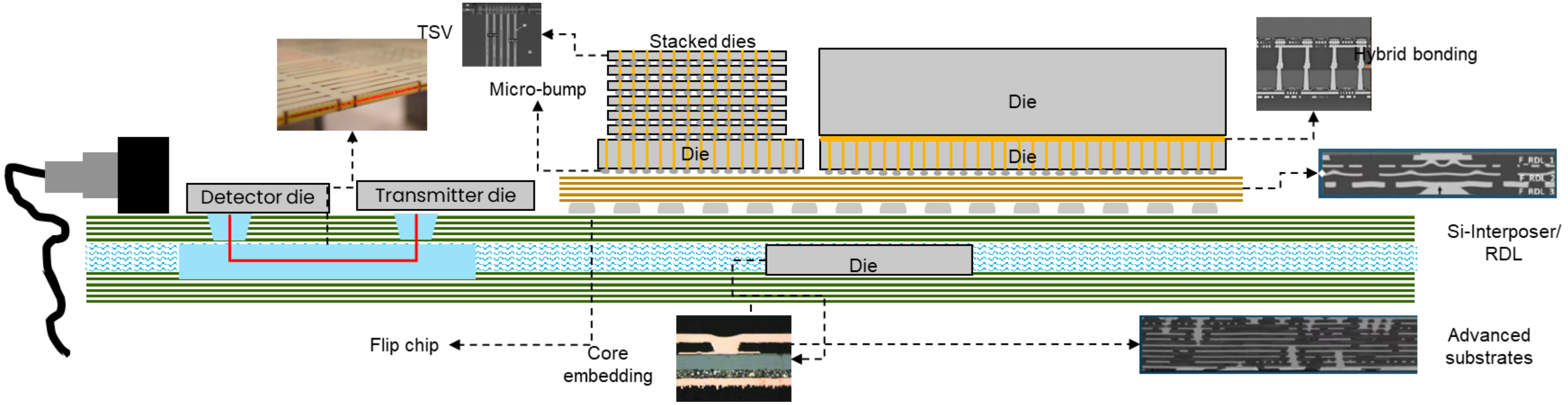
Source: IEEE Heterogenous integration roadmap 2019, Chapter 1, page 4

Heterogeneous integration

- 2D scaling is slowing down and becoming more expensive!
- More and more (sub)system focus drives increased requirements for silicon and packaging.
- Making the right choice between the on silicon (single/ multiple) and in/on package is critical for cost effective solutions.

Key enabling technologies

- Advanced packaging using 2.5D (*interposer*) & 3D (*TSVs*)
- High density interconnects (μ bumps, hybrid bonding, fine pitch RDLs)
- Thermal interfaces & heat spreaders
- Multi technology integration (CMOS, SiGE, GaN, InP and PICs)
- Co-Design tools



Cartoon inspiration: Applied materials on 2D and 3D interconnects ,Image sources: **TSV**: Jeffrey P Gambino, Microelectronic Engineering, Vol 135, 5March ., pg: 73-106 (IBM research), **Hybrid bonding**: BESI Austria

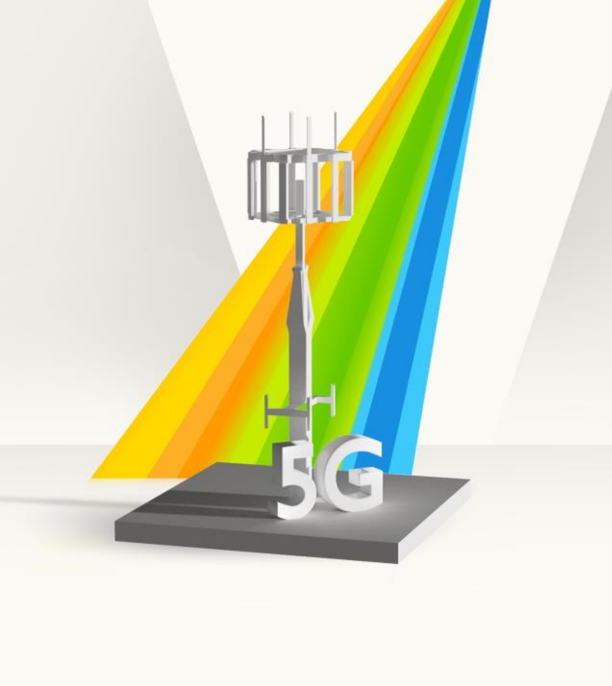
Applications

Challenges in heterogeneous integration for analog and mixed signal devices.

Millimeter wave

Automotive radar

Communication infrastructure



NXP have active in the field of analog and mixed signal semiconductor components

Analog Front Ends (AFEs)

High-Speed Multiplexers and Switches

Voltage Level Translators

Comparators and Analog Switches

Real-Time Clocks (RTCs)

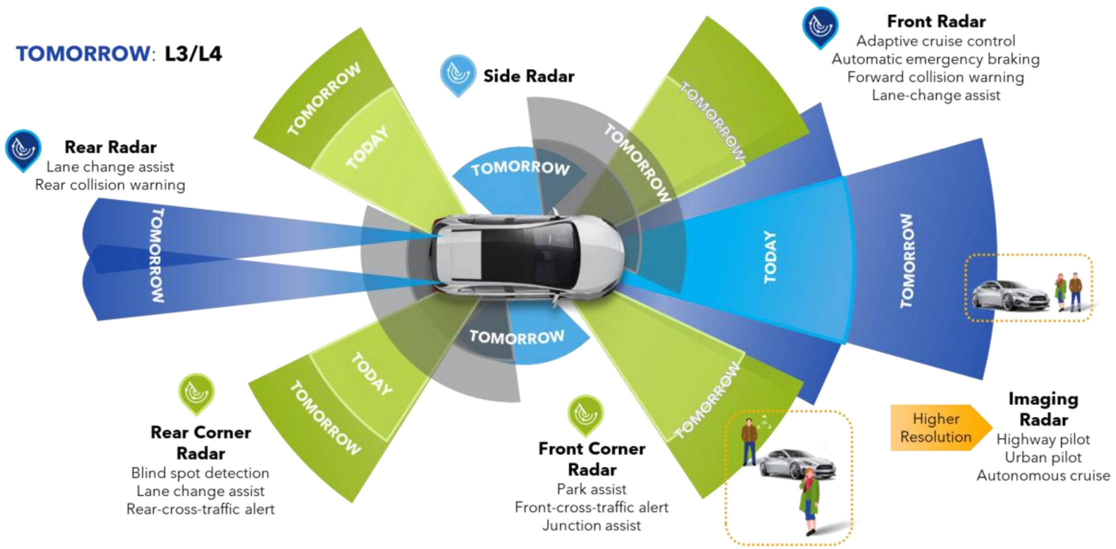
Wireless and Connectivity

Automotive Mixed-Signal Solutions

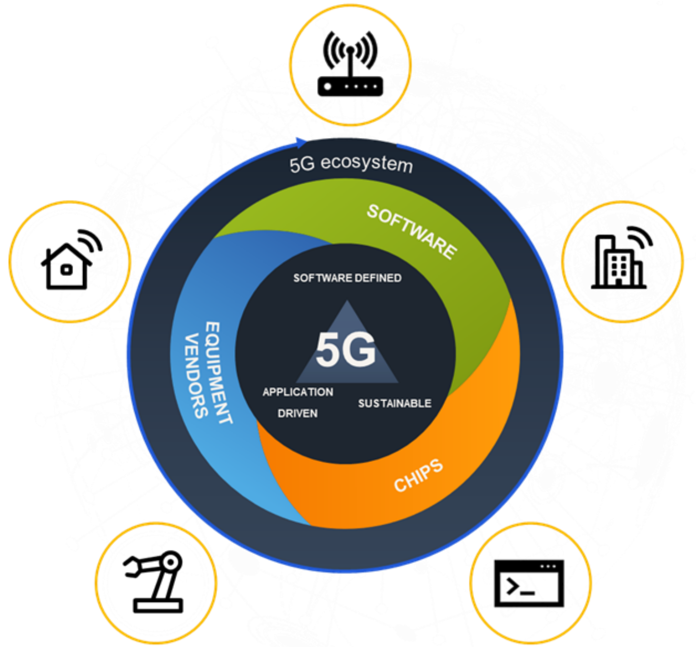
Heterogeneous integration challenges

Millimeter wave applications

Automotive radar



Communication infrastructure



Functional Driver	Automotive Radar	Communication infrastructure
Performance	High resolution and accuracy for object detection	High throughput and low latency for communication
Size	Compact form factor for integration into vehicles	Compact size for deployment in urban environments
Power Efficiency	Low power consumption for battery-operated systems	High power efficiency to reduce operational costs
Integration Complexity	Moderate complexity (RF, analog, digital integration)	High complexity (multiple RF channels, digital processing)
Thermal Management	Effective heat dissipation to maintain performance	Advanced thermal management for high-power RF components
Cost	Cost-effective solutions for mass production	Cost-effective solutions for large-scale deployment

Integration: Radar system-on-chip

Sense
Everything aware

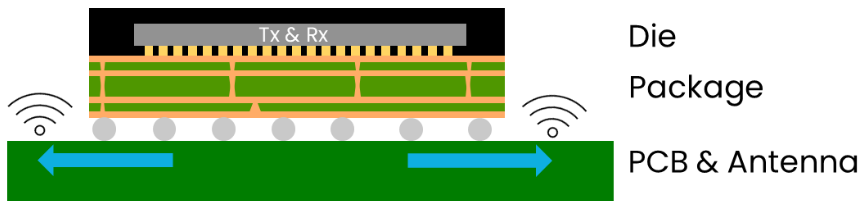
Automotive FMCW radar

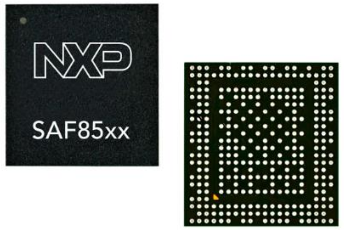
- 4 Tx, 4 Rx, ADC conversion, phase rotator, low-phase-noise VCO

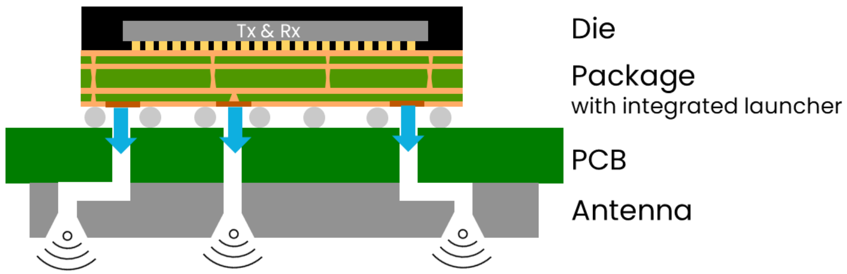
Think
Everything smart

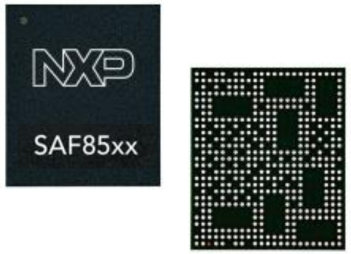
32-bit microprocessor

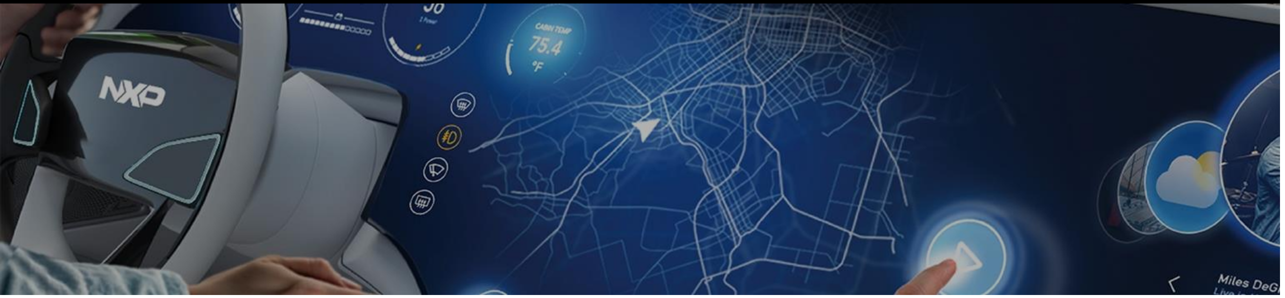
- High-performance radar processing with integrated Vector DSP











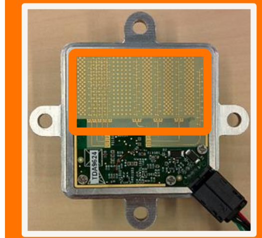
Integration: Radar system-on-chip

Sense
Everything aware

Vehicle autonomy is limited by how far & how clearly we can see

Improving detection requires integration

- Signal transfer, launch, receive

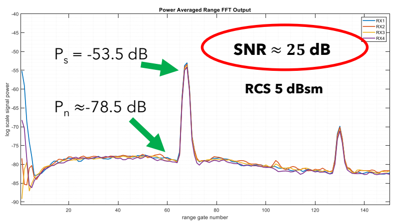


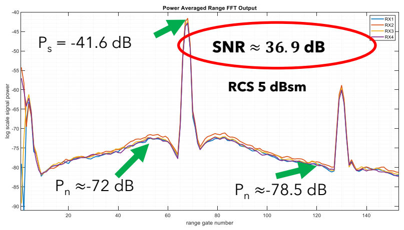
SAF85xx based sensor with PCB antenna

SAF85xx based sensor with launcher in package & 3D waveguide antenna

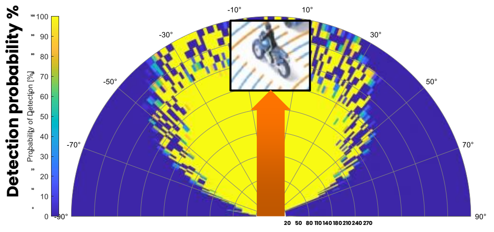
~12dB signal-to-noise ratio (SNR) improvement

= 8 .. 9dB routing & coupling losses delta + 3dB antenna directivity difference



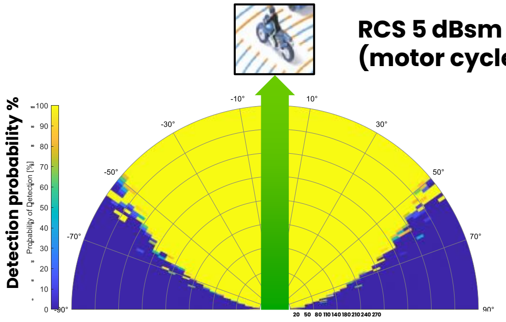


RCS 5 dBsm (motor cycle)



200m+ detection range with PCB antenna

RCS 5 dBsm (motor cycle)



Up to 400m detection range with launcher in package + 3D waveguide antenna

Integration: Active antenna amplifier system

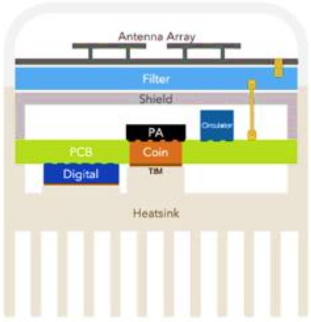
Act
Everything efficient

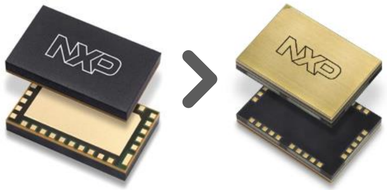
Multi-chip integration with embedded heat management

- Combines LDMOS and GaN analog semiconductors

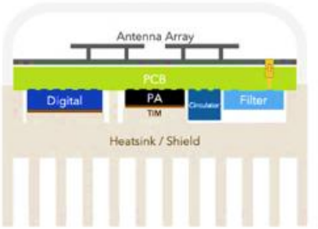
5G radio: 32 transceivers; 200 W output power

Conventional Radio

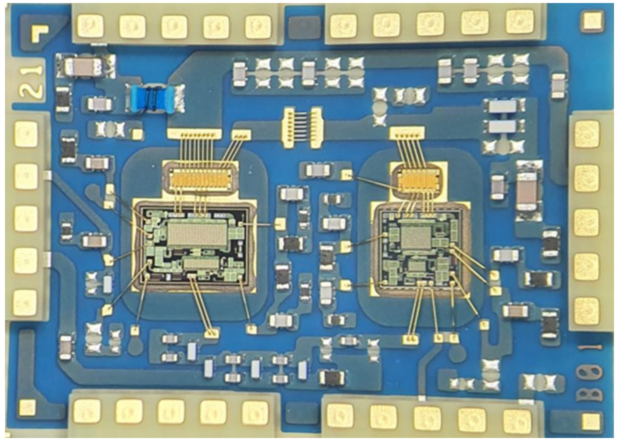




Thin MIMO Radio
Enabled by superior thermal path



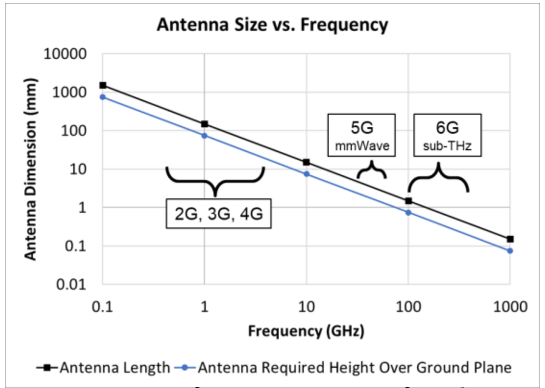
Enables passive cooling and ~40% weight reduction vs. earlier generation



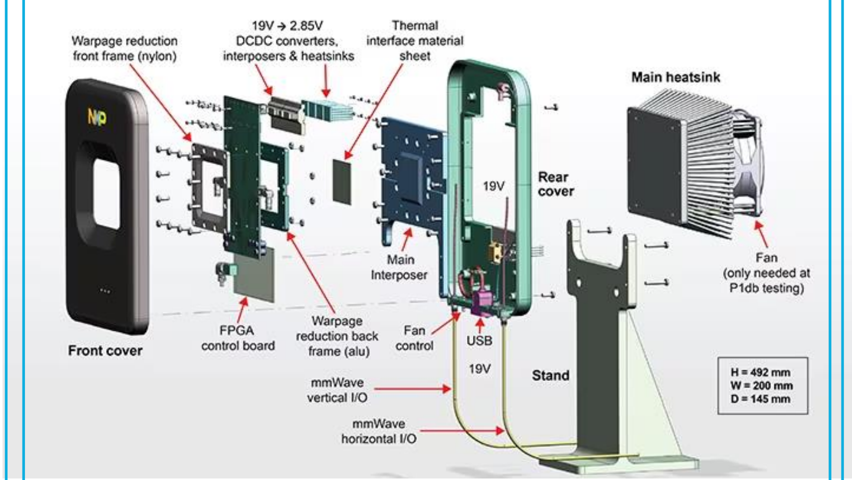
Courtesy: Ericsson

Addressing integration challenges

Antenna designs becomes critical

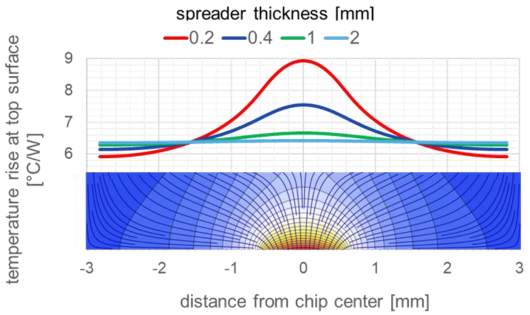


- **Antenna sizes scales with frequency**
- ≥6G, antenna-in-package becomes feasible, enabling system miniaturization



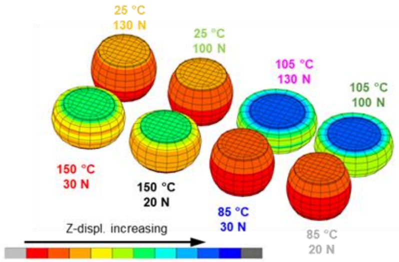
Exploded view of the NXP 5G mmWave antenna demo

Advanced Thermal Solutions

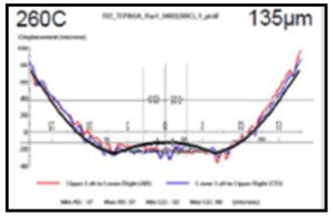


- **Co-design** of package and system thermal solutions is key.
- New interface materials and solutions needed

Reliability



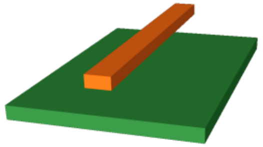
solder joint deformation



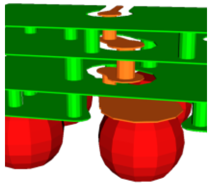
BGA substrate warpage

- **Materials** characterization (thermoelastic/fatigue)
- **Modeling** stress and deformation (Influence of process induced variations)

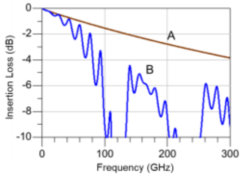
Signal Integrity & Structures



A. Ideal transmission: uniform microstrip

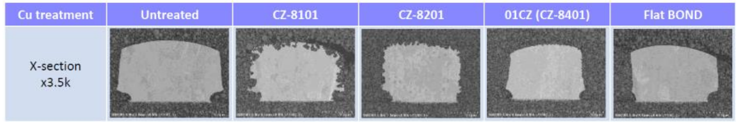


B. Traditional package: BGA structure



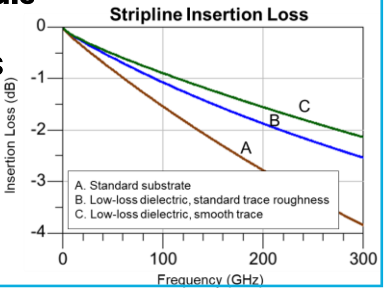
- **Traditional design have limitations (**Discrete-vias, broken-reference planes, BGA structures)
- **Package-Chip co-design critical**
  Intensive shielding, Minimizing transitions & discontinuities in signal path

Materials



Low-loss (low-D_F& D_K)
- dielectrics are critical

Need to enable new materials
- Explore novel material combinations such as substrate-integrated waveguides
- Explore use of metamaterials

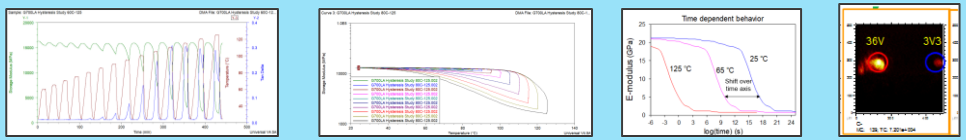


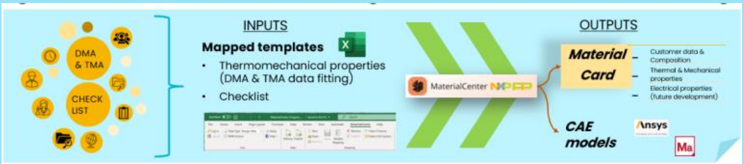
Material roadmap

- Material development
  - Comprehensive development procedure for all material classes (epoxy molding compounds, die attach, Substrates, solderballs, leadframes)

- PHASE 1
  - ✓ Set requirements and Identify available materials
  - ✓ 1st order simulations
  - ✓ Materials characterization and model refinement
- PHASE 2
  - ✓ Workability
  - ✓ Process Windowing
  - ✓ FEMA & Reliability Assessment
- PHASE 3
  - ✓ Full Qualification
  - ✓ Extended reliability & failure mode analysis
  - ✓ Documentation

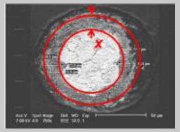
- Material characterization
  - Exhaustive techniques to perform materials characterization (thermo-mechanical, physical, chemical)
  - Database to standardize input for thermos mechanical simulations



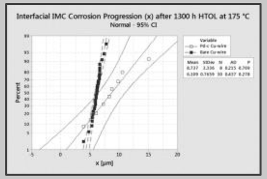


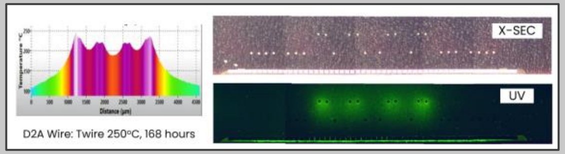
- Sustainability considerations
  - Follow regulations (e.g., REACH) and make all material compliant
  - Prepare for new items like PFAS
    - strategy to address short term needs
    - new materials PFAS-compliant
  - Work on sustainable package technologies (reduction of CO_2 footprint), including circularity by collaboration with suppliers and institutes

- Materials and reliability
  - Design materials to meet steadily increasing requirements:
    - Include a robustness margin
    - Mission profile assessments
  - Enable extended mission profiles/extreme environment applications



$$x = \sqrt{D_0 \exp\left(-\frac{E_a}{kT}\right) t}$$



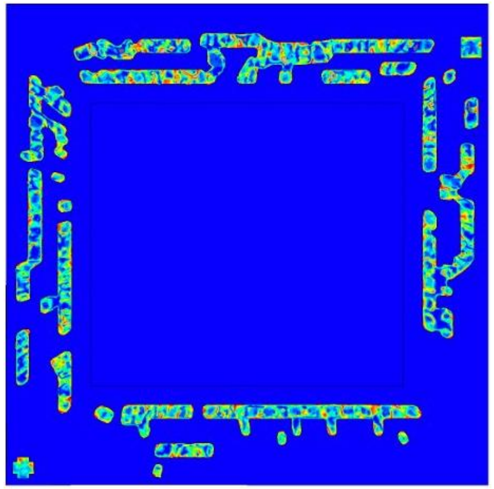


Mechanical & Thermal simulation: reducing empiricism & accelerating NPI/NTI

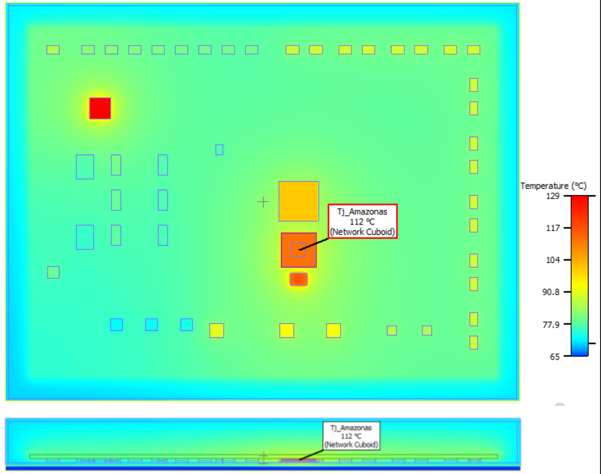
- Simulation models build using:
  - Package platform knowledge
  - Deep understanding of materials
  - Knowledge of physics of failure/degradation

- Enabling:
  - NPI design screening and BoM preselection
  - Assembly manufacturing process development
  - Customer system analysis; full analysis or support with models
  - CQC support for root cause hypothesis checking, containment selection and support of risk assessments

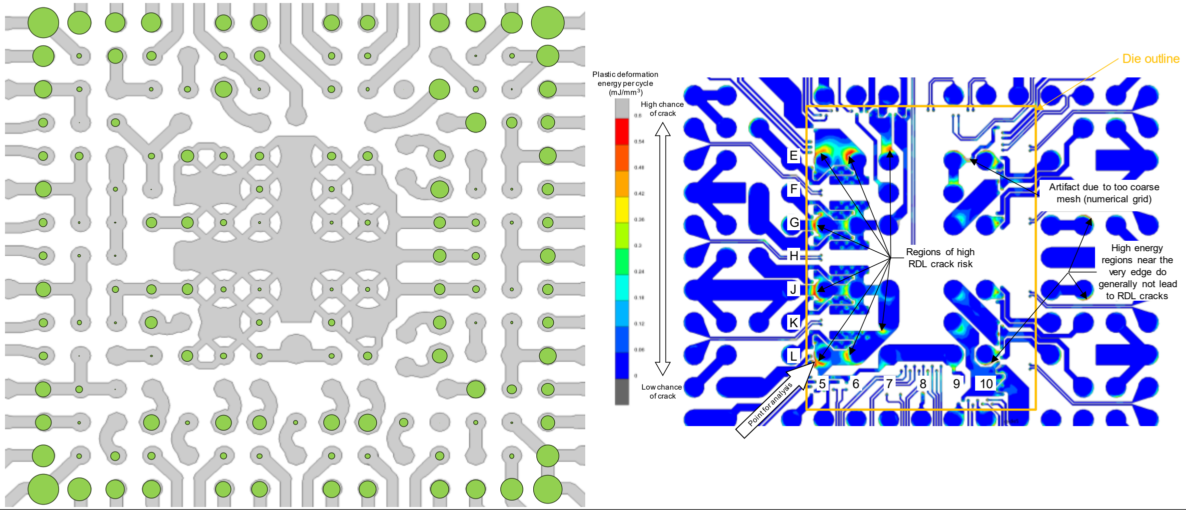
Delamination risk assessment



Thermal system analysis



BLR predictions; solder joint and RDL



Summary

Heterogeneous integration in packaging is essential to fuel growth

Challenges in integration, such as power and thermal needs to be addressed. Co-design, thorough understanding of materials and modeling needed

A diverse range of packages at the right cost point is needed.

The future is bright.

Brighter
Together

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